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Effects of methods of exposure to Eastern red cedar foliage on cedar consumption by Boer crossbred wether goats

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Abstract

Twenty-four Boer crossbred yearling wethers (23.5±2.31 kg initial BW) were used to determine effects of stepwise increases in dietary level of Eastern red cedar (*Juniperus virginiana*) foliage (CF), compared with a constant relatively high level and subsequent availability of low-quality forage, on present and later consumption of CF. Animals were penned individually in Phases 1 (8 week) and 3 (2 week), and during Phase 2 (6 week) wethers were kept in a pasture not containing cedar trees and were fed wheat hay. In Phase 1 a concentrate-based diet (CBD, 12.6% CP and 35.5% NDF) was offered at approximately 85% of the maintenance energy requirement alone (Control) or with weekly stepwise (Step) increases in level of substitution of CF for CBD (0, 1.25, 2.5, 5, 10, 15, 20, and 25% in week 1–8, respectively; DM basis) or substitution of 25% CF in week 2–8 (Set). In Phase 3 (2 week), all wethers were offered the diet of 75% CBD and 25% CF as previously, without or with separate free-choice access to low-quality grass hay. CF was harvested weekly, refrigerated and hand-mixed with CBD prior to feeding. In Phase 1, intake of CF as a percentage of that offered was greater ($P < 0.05$) for Step versus Set in week 2–8 (week 2: 84 and 68; week 3: 86 and 48; week 4: 89 and 56; week 5: 90 and 71; week 6: 96 and 81; week 7: 93 and 63; week 8: 96 and 84), although CF intake as g per day was greater ($P < 0.05$) for Set versus Step in all but week 7 and 8. In Phase 3, CBD intake was similar among treatments, and hay intake when offered averaged 149, 134 and 124 g per day for Step, Set and Control, respectively. For wethers not receiving hay, CF intake as g per day for Step was greatest among treatments ($P < 0.05$) but was not different from treatments with offered hay (67, 37, 30, 55, 53 and 56 g per day for Step, Set and Control without and with hay, respectively; S.E. = 7.1). Similarly, CF intake as a percentage of that offered ranked ($P < 0.05$) Step > Set > Control without hay, but was not different between Step without hay and treatments with hay (78, 41, 34, 61, 57 and 60% for Step, Set and Control without and with hay, respectively; S.E. = 7.6). Concentrations of various blood constituents at the end of Phases 1 and 3 did not indicate adverse health effects of CF consumption. In conclusion, gradual increases in dietary level of CF deserve further research as a potential means to elevate present and future CF consumption, with attention also directed to effects of type and level of other feedstuffs offered.

Keywords: Goats; Eastern red cedar; Feed intake

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1. Introduction

Eastern red cedar (*Juniperus virginiana*; ERC) is an invasive plant species of considerable importance in a large part of the US. Invasion of grazing lands by juniper species decreases forage availability for livestock and wildlife because of their use of nutrients, shading and lessening of deep percolation of water (Taylor et al., 1997). Junipers such as ERC also pose significant risks for wildfires. Control measures for junipers are available but most are either inefficient or expensive (Stone, 1998). One effective method of control of cedar encroachment is fire, but many factors limit potential for its use and efficacy. Consequently, there is need for alternative juniper management practices.

Goats have been shown to be effective in brush control (Dabaan et al., 1997; Luginbuhl et al., 1999), and goats can consume ERC (Thompson and Swartz, 1990; Bauni, 1993). Bauni (1993) noted ERC utilization of 17 and 45% for lightly stocked and heavily stocked pastures, respectively, by Angora goats. Heavy stocking rate also resulted in a higher browse line and more gradual decline in utilization with increasing height compared with a distinct browse line of 0.75 m for the light stocking rate. However, cedar consumption is typically much greater in fall and winter than in summer, particularly with low availability of palatable browse species (Bauni, 1993) and possibly due to reduced concentration of volatile oils at those times (Riddle et al., 1996).

Intake levels of ERC by goats are generally low. But, prior exposure of ruminants to plants with secondary metabolites can increase their later consumption (Foley et al., 1999). Training ruminants for ingestion of plants with secondary metabolites appears most effective at young ages, and 'memory' of earlier consumption is relatively long (Provenza, 1991, 1996). However, this area has been little studied with junipers. Pritz et al. (1997) bolused Spanish and Angora goats at 6–7 week of age over a 32-day period (every other day) with essential oils distilled from redberry juniper, followed by offering of fresh juniper branches. However, measures including blood enzyme levels indicated that use of the distilled essential oils may not have simulated effects of actual juniper foliage well. Bisson et al. (2001) investigated use of activated charcoal with feeding of ashe and redberry junipers to Boer crossbred goats. Although charcoal had little impact on juniper consumption, even with only 5 days of exposure juniper intake increased with advancing time.

Increased detoxification by ruminal microorganisms of plant secondary metabolites is important in the adaptation of ruminants to some plants (Freeland and Janzen, 1974). However, that ruminants within a herd differ in propensity for juniper consumption (Warren et al., 1983) suggests that microbial modifications of secondary metabolites may not be a key component of adaptation to juniper and increased intake with repeated or prolonged exposure. Rather, increases in synthesis in the liver of enzymes that detoxify or modify secondary metabolites for greater excretion (e.g. P450 enzyme systems; Cheeke, 1994) with little or no tissue (e.g. hepatic) damage (Foley et al., 1999) may be of relatively greater importance. Also, for plants such as junipers, an adaptation period may be important for becoming accustomed to unique smell and taste.

Because of the appreciable negative impacts of junipers and the current lack of suitable controls, this experiment was conducted to determine the potential for developing training schemes to enhance the ability of goats for use in ERC management strategies. The specific objective of this study was, therefore, to determine effects on later ERC consumption of stepwise increases in the dietary level of ERC, as compared with an abrupt dietary introduction of a set level of ERC or no prior ERC exposure.

2. Materials and methods

2.1. Animals and locations

Twenty-four yearling Boer crossbred (75% Boer and 25% Spanish) wethers (23.5 ± 2.31 kg initial BW) were used in an experiment with three phases. Phases 1 and 3 were conducted with individual housing in 1.1 m × 1.2 m elevated pens with plastic-coated expanded metal floors and free access to water. During Phase 2 wethers were in a pasture with dormant grass and not containing ERC, and were given free choice access to wheat hay. Wethers were vaccinated for clostridial organisms with Covexin 8 (Schering-Plough, Kinilworth, NJ) before the experiment, and were treated for internal parasites (Ivomec

Table 1
Feed ingredient composition of the concentrate-based diet consumed by Boer crossbred goat wethers

Ingredient	DM (%)
Wheat middlings	19.50
Dehydrated alfalfa pellets	15.00
Ground corn	19.19
Soybean meal	2.46
Cottonseed hulls	15.00
Molasses	5.00
Oats	19.50
Dicalcium phosphate	0.05
Limestone	1.34
Vitamin premix[a]	0.67
Trace mineralized salt[b]	0.67
Ammonium chloride	0.67
Deccox[c]	0.45
White salt	0.50

[a] Contained 2200 IU Vitamin A, 1200 IU Vitamin D_3 and 2.2 IU Vitamin E per gram.
[b] Contained 95–98.5% NaCl and at least 0.24% Mn, 0.24% Fe, 0.05% Mg, 0.032% Cu, 0.011% Co, 0.007% I and 0.005% Zn.
[c] Rhone-Poulenc, Atlanta, GA; 0.5% decoquinate.

orally; Merck Ag Vet Division, Rahway, NJ) at the beginning of Phases 1 and 3.

2.2. Phases and treatments

Lengths of Phases 1, 2 and 3 were 8, 6 and 2 week, respectively. The length of Phase 1 was based on the number of step-wise increases in CF to be employed, and that for Phase 3 was chosen to evaluate effects of previous CF exposure with minimal effect of adaptation in this second period of CF feeding. There were three dietary treatments in Phase 1, and in Phase 3 the treatment arrangement was a 3×2 factorial. There were eight goats per Phase 1 treatment and four for each dietary treatment in Phase 3.

In Phase 1, the three treatments were denoted as Step, Set and Control. Control entailed consumption of a concentrate-based diet (CBD; Table 1). For Set, CBD was consumed in week 1, and in week 2–8 the diet consisted of 75% CBD and 25% ERC foliage (CF). For Step the dietary proportion of CF increased and that of CBD decreased as week of Phase 1 advanced, with CF levels of 0, 1.25, 2.5, 5, 10, 15, 20 and 25% of DM offered in weeks 1–8, respectively.

The feeding level of CBD when at 100% of the total diet was 85% of the estimated ME requirement for maintenance of goats incurring normal pen or stall activity (i.e., 89 kcal ME/kg $BW^{0.75}$; NRC, 1981), in order to maximize the likelihood of CF consumption. The total quantity of DM offered when CF was substituted for CBD was the same as when CBD was 100% of the diet. The calculated TDN concentration in CBD was 66%, assumed to be equivalent to 2.39 kcal ME/kg DM (66% × 4.409 Mcal DE/kg, 1 kcal ME = 0.82 kcal DE; AFRC, 1998). Thus, the feeding rate was 37.2 g DM/kg $BW^{0.75}$. CBD had slightly higher amounts of minor ingredients (e.g., trace mineralized salt) than normally used, so as to ensure adequacy when CF was substituted for CBD. Likewise, the CP level was formulated to be slightly more than required for wethers of about 1 year of age.

CF was harvested weekly in Phase 1 from 25 ERC trees located on E (Kika) de la Garza American Institute for Goat Research land. Near the end of Phase 1, enough CF for Phase 3 was harvested as well. CF was stripped by hand from male tree branches below a simulated browse line of 1.5 m. After harvest, plastic bags with CF were refrigerated until feeding. Samples of CF were collected at harvest and stored at −20 °C. Another sample from the same trees was obtained 20 days after harvest of Phase 3 CF. This material was refrigerated and a subsample was removed daily for 7 days and stored at −20 °C to assess loss of volatiles during refrigeration. The amount of CF needed each day for feeding was removed from the refrigerator. At feeding CF was separated from woody plant parts but with minimal handling to avoid disruption of foliage cells, and was thoroughly hand-mixed with CBD.

In Phase 2, wethers were housed together in a pasture with dormant grass and no ERC trees, with free-choice access to wheat hay. In Phase 3, animals on each Phase 1 treatment were further divided into two sets of groups. All six groups were fed the diet of 75% CBD and 25% CF as in Phase 1. However, one set of groups also had free-choice access to coarsely ground prairie hay in a separate feed container. Thus, these animals were given a choice between a high quality diet with CF and a lower quality diet.

Diets were fed once daily at approximately 13:30 h after removal and weighing of feed refusals. Feedstuffs were sampled daily and used to construct weekly

composites. Composite feedstuff samples were kept frozen until analysis. Feed refusals were sampled on the middle day of each week, and were frozen after collection.

Wethers were weighed at the beginning and end of each phase. Blood was sampled via jugular venipuncture from 12 goats (four goats from each treatment of Phase 1 and two from each treatment of Phase 3) at the end of week 1 of Phase 1, end of Phase 1, beginning of Phase 3 and end of Phase 3. Samples were placed in ice after sampling and analyzed the same day for an array of constituents, some of which reflect health status such as liver or kidney damage.

2.3. Laboratory analyses

Partial DM concentration in CBD, CF, hays and feed refusals was determined by drying in a forced-air oven at 55 °C. Thereafter, samples were ground to pass a 1 mm screen before analysis for DM (100 °C), ash, Kjeldahl N (AOAC, 1990) and NDF (filter bag technique; Ankom Technology Corp., Fairport, NY, USA). Feedstuff samples were also analyzed for in vitro DM digestibility (filter bag technique; Ankom Technology Corp.), with ruminal fluid collected from two goats grazing native grass pasture and supplemented with a moderate amount of concentrate.

CF samples were analyzed for terpenes at the USDA ARS Jornada Experimental Range (Las Cruces, NM) following the method described by Tellez et al. (1997). Briefly, 20 g of CF (outer 8 cm of current year's growth) was steam distilled in duplicate. Oil was collected in pentane, solvent was removed with a rotary evaporator, an aliquot was resuspended in pentane containing the internal standard (γ-gurjunene) and analyses were performed by gas chromatography/ion trap mass spectrometry. Compounds were identified by comparing mass spectra and retention indices to authentic compounds or literature data (Adams, 1995). Blood samples were analyzed at Oklahoma State University Diagnostic Lab (College of Veterinary Medicine, Stillwater, OK) for sodium, potassium, chloride, carbon dioxide, anion gap k^+, urea N, creatinine, phosphorous, glucose, calcium, total protein, albumin, globulin, total bilirubin, lactate dehydrogenase (LDH), alkaline phosphatase (AP), creatine kinase, γ-glutamyltransferase (GGT), aspartate aminotransferase (AST), magnesium and osmolality.

2.4. Statistical analyses

Based on visual appearance, feed refusals in week 2–8 of Phase 1 appeared to be CF. To further evaluate this observation, necessary to determine separate intakes of CF and CBD, estimated total DM intake based on this assumption was compared with intake determined from amounts of feedstuffs offered and DM concentration in feedstuffs and orts using GLM procedures of SAS (1990) and a model consisting of dietary treatment, method of determination and their interaction. DM intake was not affected by method of determination or the interaction between dietary treatment and method ($P > 0.10$). Intake data in Phase 1 were analyzed separately for each week with a model consisting of treatment (i.e., Control, Set and Step). Intake data of Phase 3 for week 1, 2 and 1–2 were analyzed with a model consisting of Phase 1 treatment, hay access in Phase 3 and their interaction. Differences among means were determined by LSD with a protected F-test ($P < 0.05$). Initial BW was used as a covariate in the analysis of ADG and blood constituent concentrations at the beginning of Phase 1 were used as covariates in the analysis of blood constituents at the end of Phase 1 and beginning and end of Phase 3.

3. Results and discussion

3.1. Feedstuff composition

Composition of feedstuffs is in Table 2. CF averaged 48% DM, 33% NDF and 6% CP, comparable to values reported by Thompson and Swartz (1990). This low level of CP suggests that CP intake could limit performance with diets high in CF regardless of potential adverse effects of terpenoids. Relatedly, Pritz et al. (1997) noted that juniper consumption negatively affected N balance, and suggested that dietary protein supplementation may be of particular importance in achieving high consumption of juniper.

Concentrations of DM, ash, N and NDF and IVDMD for CF did not vary markedly among times of harvest or sampling. Some research has indicated negative effects of monoterpenes on IVDMD because of microbial toxicities (Oh et al., 1967; Schwartz et al., 1980). It is not possible to discern if this occurred in the present experiment. IVDMD was only slightly

Table 2
Composition of feedstuffs consumed by Boer crossbred goat wethers

Phase[a]	Week	Feedstuff	Item				
			DM[b]	Ash[c]	NDF[c]	N[c]	IVDMD[d]
1	1	Concentrate-based diet	87.2	10.3	37.8	2.21	72.0
	2	Concentrate-based diet	87.0	5.7	31.6	1.93	73.5
		Cedar foliage	49.2	6.5	32.3	0.94	67.4
	3	Concentrate-based diet	87.7	6.5	35.4	1.74	73.8
		Cedar foliage	47.9	5.3	31.6	0.96	68.6
	4	Concentrate-based diet	87.3	6.5	32.7	2.10	74.0
		Cedar foliage	48.5	5.1	33.7	0.95	68.4
	5	Concentrate-based diet	87.8	7.0	34.5	2.11	75.0
		Cedar foliage	48.1	5.3	32.6	0.96	68.2
	6	Concentrate-based diet	87.9	5.4	38.4	1.94	71.2
		Cedar foliage	48.5	4.9	32.3	1.00	68.1
	7	Concentrate-based diet	88.6	5.9	40.7	2.06	72.2
		Cedar foliage	49.1	4.8	32.2	1.00	69.1
	8	Concentrate-based diet	88.8	5.8	35.1	1.83	71.2
		Cedar foliage	48.1	5.0	34.0	1.05	66.9
2		Wheat hay	89.4	7.4	63.3	0.75	65.0
3	1	Concentrate-based diet	88.1	6.1	37.7	2.00	72.9
		Cedar foliage	48.0	5.2	33.4	0.94	67.7
		Prairie hay	87.5	6.5	61.9	0.71	56.1
	2	Concentrate-based diet	87.7	7.4	31.7	2.23	77.3
		Cedar foliage	46.7	4.6	31.9	0.94	68.9
		Prairie hay	87.4	7.2	63.2	0.76	54.1
Mean		Concentrate-based diet	87.8	6.7	35.5	2.02	73.3
		Cedar foliage	48.2	5.2	32.7	0.97	68.1
		Prairie hay	87.5	6.9	62.6	0.74	55.1

[a] 1: 8-week-period of adaptation to eastern red cedar foliage, with weekly harvests; 2: 6-week period; 3: 2-week period.
[b] In %.
[c] % DM.
[d] In vitro DM digestion, %; filter bag technique with NDF as the end-point measure.

less than that of the concentrate-based diet. However, with NDF as the end-point measure, IVDMD and the NDF concentration indicate that if there were no microbial toxicities, very little if any NDF was digested.

3.2. Terpenoid composition of CF

Total oil yield of CF was fairly high, particularly in Phase 3 (Table 3). Total oil was found negatively related to intake by deer of various *Juniperus* species (Schwartz et al., 1980; Riddle et al., 1996). Sabinene, limonene, safrole, terpin-4-ol and elemol were present in highest concentrations in CF. Similarly, von Rudloff (1975) reported limonene and sabinene to be the major peaks in *J. virginiana* oil but identified only a few (<10) compounds with certainty. Adams and Hogge (1983) conducted a more thorough examination of compounds in this species (approximately 40) and reported that sabinene, limonene, safrole and elemol + elemicin were primary peaks (>5% of total oil). von Rudloff (1975) compared concentrations of major monoterpenes in *Juniperus virginiana* from different locations and among and within trees at the same location, and noted high variability among trees and locations. Although there was substantial variability from week to week for many of the individual compounds in the present experiment, no obvious trends over time were evident. Terpene levels typically vary from plant to plant, as well as due to stage of phenology and environmental factors (Riddle et al., 1996). With the exception of myrcene, concentrations

Table 3
Oil and terpene concentrations in eastern red cedar foliage fed to Boer crossbred goat wethers

Item	Phase 1[a]							
	Week 2	Week 3	Week 4	Week 5	Week 6	Week 7	Week 8	Phase 3[b]
Total oil yield (% DM)	1.82	1.84	2.31	2.89	2.18	2.13	2.26	3.18
Concentration of compounds (μg/g DM)								
Alpha-thujene	322	206	277	270	231	242	161	242
Alpha-pinene	334	209	318	257	230	198	192	253
Sabinene	3699	2813	4970	4223	3519	2875	2609	4305
Myrcene	322	93	259	254	103	113	127	142
2-Carene	155	117	175	382	178	120	116	1
Alpha-phellandrene	36	13	24	37	16	17	11	17
3-Carene	4	2	3	134	5	10	2	22
Alpha-terpinene	536	299	445	431	305	296	253	387
p-Cymene	26	14	21	23	26	19	16	22
Limonene	1718	611	1017	2195	1634	513	1448	565
1,8-Cineole	46	8	33	76	38	15	14	64
Gamma-terpinene	740	396	576	554	418	449	318	488
cis-Sabinene_hydrate	31	32	49	57	33	38	35	56
Terpinolene	276	152	213	239	145	151	132	191
Linalool	247	177	374	498	127	159	112	237
trans-Sabinene_hydrate	3	15	3	3	34	45	35	48
cis-para-Menth-2-en-1-ol	88	41	59	95	36	53	42	58
trans-para-Menth-2-en-1-ol	45	23	30	49	18	35	25	32
Citronellal	9	5	7	22.3	6	6	9	12
Terpin-4-ol	1556	935	1245	1319	898	866	687	1128
Alpha-terpineol	53	26	40	44	21	32	21	34
Methyl_chavicol	10	27	22	70	22	31	44	72
Citronellol	129	21	40	67	66	80	68	148
Safrole	1435	1737	2454	3093	1720	1353	1980	3233
Methyle_eugenol	458	550	749	927	455	368	658	970
E-Caryophyllene	17	5	23	24	17	9	40	32
Germacrene_D	6	5	11	8	10	11	7	14
trans-Gamma-cadinene	26	24	27	39	31	39	22	35
Delta-cadinene	112	79	124	206	100	83	114	167
Elemol	1580	1245	1546	1769	1527	1555	1548	1879
Elemicin	118	265	345	567	222	225	380	559
Beta-oplopenone	14	15	18	36	30	21	25	34
10-Epi-gamma-eudesmol	9	7	7	7	4	18	12	18
Gamma-eudesmol	176	123	127	152	101	140	165	197
Epi-alpha-Cadinol	80	120	103	148	93	75	103	142
Beta-eudesmol	126	104	131	139	103	143	171	185
Alpha-eudesmol + alpha-cadinol	266	307	294	363	216	255	351	414
Bulnesol	15	17	21	23	10	21	34	36
8-Alpha-acetoxyelemol	155	597	393	415	426	382	664	626

[a] Week of Phase 1.
[b] Collected at the end of Phase 1, 8-week before Phase 3.

of α-pinene, sabienene, cymene, limonene and terpineol were similar to values reported by Riddle et al. (1996) and Pritz et al. (1997) for redberry juniper but differ from levels in ashe juniper (Riddle et al., 1996).

Some studies have indicated that as much as 80% of monoterpenes in sagebrush may be lost during mastication by deer and rabbits (Cluff et al., 1982; White et al., 1982). Nonetheless, monoterpene concentrations in plants have correlated negatively with feed

intake by herbivores (Riddle et al., 1996; Estell et al., 1998a). Vourc'h et al. (2002) reported that sabinene, myrcene, α-pinene, limonene and α,β-thujone were deterrents to feed consumption by deer, with increased repellency as concentrations of the monoterpenes rise. This could be attributed partially to monoterpene odor or taste (Elliott and Loudon, 1987; Narjisse et al., 1996); although, rejection based on monotepene odor may lessen with advancing time (Elliott and Loudon, 1987). Riddle et al. (1996) reported for Angora and Spanish goats that α-pinene, sabinene + β-pinene, myrcene, limonene and terpineol were negatively correlated with juniper intake, whereas cymene was correlated positively. Conversely, sabinene, *p*-cymene, 1,8 cineole, 3-carene, limonene, myrcene and β-pinene applied to alfalfa pellets did not depress intake of alfalfa by sheep, but α-pinene had a negative effect (Estell et al., 1998b, 2000, 2002). However, in these studies levels of monoterpenes used were based on those found in *Flourensia cernua* (Estell et al., 1998a), which were lower for most of the terpenes than observed in CF of this experiment. One reason compounds may be correlated with intake but not related to intake when applied individually is because volatiles may serve as cues for other toxic compounds (Lawler et al., 1999). These workers initially reported that 1,8-cineole was negatively related to intake of eucalyptus by various marsupials, but determined that this compound was correlated with the actual aversive compounds (e.g., jensenone) that were not detectable. A second reason may be because literature supporting a relationship of terpenes with dietary preferences often use animals on a low plane of nutrition. However, animals consuming adequate nutrients (especially protein) may be able to consume more forage containing secondary compounds due to enhanced capability to metabolize phytotoxins (Illius and Jessop, 1996; Villalba et al., 2002).

There were few obvious trends in terpene levels related to refrigeration time, although a few compounds (e.g., sabinene) did appear to change with advancing time (Table 4). Interestingly, 2-carene was much lower in these samples than in ones collected for feeding during Phase 1. Many of the volatiles in CF used to assess effects of length of refrigeration were greater than those in Phase 1, which is likely because samples were collected approximately 3 week later than other samples.

3.3. Intake

Cedar consumption as g per day was greater ($P < 0.05$) for Set compared with Step until Step wethers were offered 20% CF, with similar CF intake in weeks 7 and 8 (Table 5). Differences among treatments in CBD intake in Phase 1 were largely because of levels offered relating to substitution with CF. Total DM intake was similar among treatments except in week 3 when intake for the Set treatment was lowest among treatments ($P < 0.05$) primarily because of low CF intake relative to that in other weeks. CF intake as a percentage of CF DM offered was consistently greater for Step than for Set from weeks 2–8 ($P < 0.05$), which suggests that Step wethers with the gradual dietary introduction of CF were able to better adapt to CF. Bisson et al. (2001) also reported that juniper intake increased as time of exposure advanced, attributing change to terpenoids in juniper. Total NDF intake was similar among treatments except in weeks 3 and 7. Intake of N varied among treatments in accordance with differences in CBD and CF intakes.

In Phase 3, CF DM intake as g per day and a percentage of that offered averaged over weeks 1 and 2 was affected by an interaction between Phase 1 treatment and hay access (Table 6). CF intake was greatest among Phase I treatments ($P < 0.05$) for Step without access to hay but was similar among Phase 1 treatments when hay was available. CF intakes for treatments with hay access was greater than for the Control without hay ($P < 0.05$) and tended to be greater than for Set ($P < 0.14$) and less than for Step ($P < 0.24$). Thus, access to hay largely negated the effect of prior exposure to and method of adaptation to CF. Other differences in intake were associated with greater total intake with than without hay availability.

That Control wethers consumed CF in Phase 3 could reflect rapidly inducible ruminal microbial or hepatic enzymes with capacity to detoxify plant secondary metabolites (Foley et al., 1999) and seems contradictory to greater Phase 3 CF intake by Step versus Set and Control wethers without hay access. Because there was not a decrease in CF intake with advancing week of Phase 1 by Set wethers, feedback aversions may not have been present or appreciable. This might indicate that limited intake of CF by goats is

Table 4
Oil and terpene concentrations in refrigerated eastern red cedar foliage sampled daily for 1 week after harvest

Item	Day[a]							
	0	1	2	3	4	5	6	7
Total oil yield (% DM)	3.28	2.88	3.08	2.84	2.86	3.24	2.69	2.81
Concentration of compounds (μg/g DM)								
Alpha-thujene	259	235	268	237	293	296	280	298
Alpha-pinene	282	272	301	299	540	355	302	290
Sabinene	4461	4202	4723	5133	5447	5440	5166	5273
Myrcene	286	246	268	295	281	295	241	211
2-Carene	0.5	0.7	0.7	0.2	0.2	0.2	0.2	0.2
Alpha-phellandrene	19	16	18	20	21	20	19	20
3-Carene	38	40	29	52	53	55	31	51
Alpha-terpinene	409	375	407	377	395	394	358	376
p-Cymene	18	14	19	22	24	20	22	24
Limonene	2925	3016	2587	2835	3089	3680	2586	2532
1,8-Cineole	102	81	96	97	120	111	94	118
Gamma-terpinene	556	536	582	540	538	498	543	604
cis-Sabinene_hydrate	55	48	49	49	54	51	45	52
Terpinolene	263	240	222	209	222	230	187	201
Linalool	59	52	149	68	83	54	95	66
trans-Sabinene_hydrate	42	45	40	40	37	39	34	40
cis-para-Menth-2-en-1-ol	65	50	53	53	55	50	46	51
trans-para-Menth-2-en-1-ol	35	27	32	33	34	32	29	33
Citronellal	11	7	8	5	5	4	4	4
Terpin-4-ol	1351	1192	1202	1177	1264	1185	1029	1117
Alpha-terpineol	40	29	32	31	30	27	25	30
Methyl_chavicol	129	94	84	98	94	104	73	129
Citronellol	251	172	90	54	57	52	33	42
Safrole	2620	2557	3542	2751	3262	3335	3215	3327
Methyle_eugenol	1045	856	928	828	789	816	642	735
E-Caryophyllene	22	15	26	26	29	31	27	29
Germacrene_D	10	8	9	5	4	5	5	3
trans-Gamma-cadinene	32	28	34	20	23	24	28	42
Delta-cadinene	132	143	176	121	139	157	158	128
Elemol	1901	1859	2021	1591	1407	1551	1334	1370
Elemicin	440	400	434	311	345	317	271	305
Beta-oplopenone	52	55	32	21	20	21	11	24
10-Epi-gamma-eudesmol	20	17	10	9	8	8	7	6
Gamma-eudesmol	197	209	179	120	109	123	95	85
Epi-alpha-cadinol	117	140	123	67	70	78	77	62
Beta-eudesmol	185	189	141	90	86	93	85	103
Alpha-eudesmol + alpha-cadinol	383	403	442	344	338	435	366	349
Bulnesol	35	32	28	20	19	20	19	14
8-Alpha-acetoxyelemol	553	611	360	159	162	163	120	122

[a] 0: day of collection, and 1–7 are days after collection while refrigerated.

primarily due to palatability, but, this would not explain effects of hay consumption on CF intake in Phase 3.

Reasons for the interaction in Phase 3 CF intake between method of adaptation to CF in Phase 1 and hay access in Phase 3 are unclear, although Taylor et al. (1997) also increased redberry juniper intake by supplementing with concentrate, with greater change noted with a supplement relatively high in CP than with one based on corn grain. Villalba et al. (2002) increased intake of sagebrush by sheep and goats by offering a high protein supplement but not with one high

Table 5
Effects of method of adaptation to eastern red cedar foliage on feed intake by Boer crossbred goat wethers fed at a level of intake near maintenance

Item	Treatment[a]				
	Week	Step	Set	Control	S.E.
Cedar DM (g per day)	1	0	0	0	0.0
	2	4 a	65 b	0 a	2.0
	3	7 a	44 b	0 a	2.5
	4	16 b	52 c	0 a	1.9
	5	33 b	65 c	0 a	2.2
	6	50 b	75 c	0 a	2.0
	7	66 b	59 b	0 a	3.2
	8	84 b	78 b	0 a	2.4
	Mean	32 b	55 c	0 a	1.3
Cedar DM (% of offered)	1	–	–	–	–
	2	84 b	68 a	–	5.1
	3	86 b	48 a	–	8.3
	4	89 b	56 a	–	5.1
	5	94 b	71 a	–	5.1
	6	96 b	81 a	–	3.8
	7	93 b	63 a	–	5.2
	8	96 b	84 a	–	2.8
	Mean	91 b	67 a	–	4.4
Concentrate-based diet DM (g per day)	1	359	397	362	17.0
	2	367 b	299 a	381 b	9.5
	3	369 b	303 a	385 b	9.5
	4	359 b	302 a	382 b	9.4
	5	341 b	303 a	392[c]	9.2
	6	323 a	304 a	392 b	9.1
	7	307 a	306 a	396 b	9.0
	8	288 a	307 a	397 b	8.9
	Mean	339 a	315 a	385 b	9.1
Total DM (g per day)	1	359	397	362	17.0
	2	371	364	381	10.1
	3	376 b	347 a	385 b	9.8
	4	374	354	382	9.3
	5	374	369	392	9.4
	6	374	379	392	9.4
	7	373	366	396	9.4
	8	372	386	397	9.8
	Mean	372	370	386	9.4
NDF (g per day)	1	135	150	136	7.1
	2	117	115	119	3.4
	3	133 b	116 a	135 b	3.8
	4	122	116	124	3.2
	5	128	125	135	3.2
	6	140	141	151	3.6
	7	146 a	143 a	161 b	3.8
	8	129	135	139	3.4
	Mean	131	130	137	3.4

Table 5 (*Continued*)

Item	Treatment[a]				
	Week	Step	Set	Control	S.E.
Nitrogen (g per day)	1	8.0	8.8	7.9	0.39
	2	7.1 b	6.4 a	7.4 b	0.18
	3	6.5 b	5.6 a	6.7 b	0.17
	4	7.7 b	6.7 a	8.0 b	0.19
	5	7.5 a	7.0 a	8.3 b	0.19
	6	6.7 a	6.6 a	7.6 b	0.18
	7	7.0 a	6.9 a	8.2 b	0.19
	8	6.1 a	6.4 a	7.3 b	0.17
	Mean	7.0 a	6.8 a	7.7 b	0.18

a and b means in a row without a common letter differ ($P < 0.05$).

[a] Step: dietary cedar foliage level (DM basis) of 0, 1.25, 2.5, 5, 10, 15, 20 and 25% in weeks 1—8, respectively; set: dietary cedar foliage level (DM basis) of 0% in week 1 and 25% in weeks 2–8; control: 0% dietary cedar foliage level.

in energy. It was suggested that sagebrush increased the need for protein based on selection by lambs of a diet with a higher protein:energy ratio in the PM after sagebrush consumption than in the AM before sagebrush was offered.

Sorensen and Dearing (2003) proposed that woodrats contend with toxins via reduced absorption (degraded or inactivated in intestines, faster passage rate), more active detoxification (greater enzymatic activity in gut and liver) or depositing in other tissues. In accordance, the interaction in Phase 3 CF intake between method of adaptation to CF in Phase 1 and hay access in Phase 3 may have been due to increased hepatic metabolism of monoterpenes because of greater nutrient intake with offering of hay. In this regard, Thomas et al. (1987) suggested that mixed function oxidase activity in the liver is influenced by nutritional plane, particularly protein absorption, with resultant change in hepatic metabolism of steroid hormones and drugs. Conversely, Freetly and Ferrell (1994) postulated that, based on splanchnic tissue progesterone metabolism by ewes fed a diet to provide energy adequate for BW maintenance or 66% of maintenance, detoxification and metabolism of potential harmful metabolites are not affected by nutritionally induced changes in liver metabolism, although plant secondary metabolites were not specifically tested. Another possibly involved factor is an expected more rapid rate of digesta passage through the gastrointestinal tract with hay consumption that could have lessened monoterpene absorption.

3.4. Average daily weight change

Wethers on all treatments lost small and comparable amounts of BW in Phase 3 (Table 7). Slightly more BW was gained in Phase 2 than was lost in Phases 1 and 3. Replacement of up to 25% CBD by CF did not accentuate BW loss in either Phase 1 or 3. The lesser quantity of BW lost by groups with than without access to hay in Phase 3 presumably was due to greater nutrient absorption resulting from increased intakes of total DM, NDF and N, although Phase 1 CF adaptation treatment and hay access in Phase 3 did not interact in ADG as was the case for CF intake.

3.5. Blood constituents

Concentrations of most blood constituents were within normal physiological ranges (Tables 8–10). Although, albumin, AST and magnesium levels were below normal physiological ranges of 2.8–3.8 g/dl, 122–321 U/l and 2.8–3.6 mg/dl, respectively (College of Veterinary Medicine, Oklahoma State University, Stillwater, OK). AP levels were above the normal physiological range of 75–228 U/l.

At the end of Phase 1, blood concentration of carbon dioxide was greatest among treatments ($P < 0.05$) for Step (Table 8), with no significant differences in other concentrations. Blood concentration of phosphorous was lowest among treatments ($P < 0.05$) for Step at the start of Phase 3 (Table 9), which was unexpected given the same treatment of wethers when on pasture in Phase 2.

Table 6
Effects of methods of adaptation to eastern red cedar foliage on subsequent DM intake of Boer crossbred goat wethers

Item	No hay[a]				Hay[a]				Treatment[b]				Hay access[a]		
	Week	Step	Set	Control	Step	Set	Control	S.E.	Step	Set	Control	S.E.	No hay	Hay	S.E.
Cedar (g per day)	1	63	35	22	44	43	48	8.9	54	39	35	6.3	40	44	5.1
	2	72	40	40	65	65	65	9.2	69	52	52	6.5	50	65	5.3
	Mean	67 c	37 a,b	30 a	55 b,c	53 b,c	56 b,c	7.1							
Cedar (% offered)	1	72	38	25	48	45	51	9.5	60	41	38	6.7	45	48	5.5
	2	84	44	45	73	70	70	10.4	79	57	58	7.3	72	58	6.0
	Mean	78 c	41 b	34 a	61 b,c	57 a,b,c	60 b,c	7.6							
Concentrate (g per day)	1	278	303	291	298	310	310	9.5	288	306	301	6.7	291	306	5.5
	2	288	302	291	300	310	309	8.2	294	306	300	5.8	294	306	4.8
	Mean	283	303	291	299	310	310	8.6	291	306	300	6.1	292	306	5.0
Hay (g per day)	1				74	96	74	23.2	37	48	37	16.4	0	82	13.4
	2				217	178	182	15.7	109	89	91	11.1	0	193	9.1
	Mean				149	134	124	16.4	74	67	62	11.6	0	136	9.5
Total DM (g per day)	1	341	338	314	416	449	433	27.1	379	394	373	19.1	331 a	432 b	15.6
	2	360	342	331	582	552	556	20.2	471	447	443	14.3	344 a	564 b	11.6
	Mean	350	340	321	503	497	490	20.5	426	418	405	14.5	337 a	496 b	11.8
NDF (g per day)	1	128	125	117	179	193	182	14.7	154	159	149	10.4	124 a	185 b	8.5
	2	114	108	105	257	239	238	9.5	185	174	171	6.7	109 a	245 b	5.5
	Mean	122	117	112	220	214	207	10.3	171	166	160	7.3	117 a	214 b	6.0
N (g per day)	1	6.0	6.3	5.9	6.7	7.1	7.1	0.32	6.3	6.7	6.5	0.23	6.1 a	7.0 b	0.19
	2	7.1	7.0	6.8	8.9	8.7	8.8	0.27	8.0	7.9	7.8	0.19	7.0 a	8.8 b	0.16
	Mean	6.5	6.6	6.3	7.8	7.9	7.9	0.27	7.1	7.2	7.1	0.19	6.5 a	7.9 b	0.16

a, b and c means in a row within each category and without a common superscript letter differ ($P < 0.05$).

[a] No hay denotes wethers that received only a 75% concentrate-based diet and 25% cedar foliage and hay denotes wethers that received hay in separate container in addition to 75% concentrate-based diet and 25% cedar foliage.

[b] Step: dietary cedar foliage level (DM basis) of 0, 1.25, 2.5, 5, 10, 15, 20 and 25% in weeks 1–8, respectively; set: dietary cedar foliage level (DM basis) of 0% in week 1 and 25% in weeks 2–8; control: 0% dietary cedar foliage level.

Table 7
Initial BW and ADG of Boer crossbred goat wethers fed at a level of intake near maintenance

Item	Treatment[a]				Hay access[b]		
	Step	Set	Control	S.E.	Hay	No hay	S.E.
Initial BW (kg)	22.6	24.5	23.6	0.80			
ADG (g per day)							
Phase 1	−26	−39	−33	5.1			
Phase 2	52	64	59	7.7			
Phase 3	−135	−136	−117	18.7	−96 a	−162 b	15.2

a and b means in a row without a common superscript letter differ ($P < 0.05$).

[a] Step: dietary cedar foliage level (DM basis) of 0, 1.25, 2.5, 5, 10, 15, 20 and 25% in weeks 1–8, respectively; set: dietary cedar foliage level (DM basis) of 0% in week 1 and 25% in week 2–8; control: 0% dietary cedar foliage level.

[b] With or without separate free-choice access to low-quality grass hay.

At the end of Phase 3, blood concentrations of albumin and total bilirubin were greatest among treatments ($P < 0.05$) for Control (Table 10). Blood concentrations of potassium and carbon dioxide were affected by an interaction between Phase 1 treatment and hay access in Phase 3. Concentration of potassium was greatest among Phase I treatments ($P < 0.05$) for Control without access to hay but

Table 8
Effects of method of adaptation to Eastern red cedar foliage on concentrations of blood constituents of Boer crossbred goat wethers fed at a level of intake near maintenance at the end of Phase 1

Item	Treatment[a]			S.E.
	Step	Set	Control	
Sodium (mmol/l)	144	145	144	0.8
Potassium (mmol/l)	5.1	5.1	5.4	0.19
Chloride (mmol/l)	107	108	107	1.0
Carbon dioxide (mmol/l)	30.5 b	28.3 a	28.2 a	0.58
Anion gap K^+ (mmol/l)	11.7	13.3	14.0	0.83
Urea N (mg/dl)	16.5	14.8	17.0	1.39
Creatinine (mg/dl)	0.90	0.96	1.05	0.062
Urea N:creatinine ratio	17.9	15.6	17.1	1.60
Phosphorous (mg/dl)	6.3	7.4	7.9	0.49
Glucose (mg/dl)	50.2	52.8	54.3	2.14
Calcium (mg/dl)	9.3	9.3	9.1	0.23
Total protein (g/dl)	6.5	6.4	6.3	0.10
Albumin (g/dl)	2.35	2.33	2.39	0.051
Globulin (g/dl)	4.1	4.0	3.9	0.10
Albumin:globulin ratio	0.57	0.58	0.61	0.021
Total bilirubin (mg/dl)	0.16	0.26	0.28	0.039
Lactate dehydrogenase (U/l)	697	787	919	60.0
Alkaline phosphatase (U/l)	494	382	422	47.8
Creatine kinase (U/l)	51	74	73	8.7
γ-Glutamyltransferase (U/l)	83.4	75.5	75.2	4.20
Aspartate aminotransferase (U/l)	69.5	76.8	74.9	4.48
Magnesium (mg/dl)	2.43	2.33	2.41	0.094
Osmolality (mosm/kg)	276	278	277	1.1

a and b means in a row without a common letter differ ($P < 0.05$).

[a] Step: dietary cedar foliage level (DM basis) of 0, 1.25, 2.5, 5, 10, 15, 20 and 25% in weeks 1–8, respectively; set: dietary cedar foliage level (DM basis) of 0% in week 1 and 25% in week 2–8; control: 0% dietary cedar foliage level.

Table 9
Effects of method of adaptation to Eastern red cedar foliage on concentrations of blood constituents of Boer crossbred goat wethers fed at a level of intake near maintenance at the start of Phase 3

Item	Treatment[a]			S.E.
	Step	Set	Control	
Sodium (mmol/l)	143	139	138	3.9
Potassium (mmol/l)	4.7	4.6	5.0	0.14
Chloride (mmol/l)	108	104	101	2.7
Carbon dioxide (mmol/l)	27.4	26.4	27.4	0.96
Anion gap K+ (mmol/l)	13.3	13.4	14.3	1.74
Urea N (mg/dl)	17.3	15.5	16.7	1.46
Creatinine (mg/dl)	0.86	0.72	0.75	0.096
Urea N:creatinine ratio	21.5	20.9	22.6	2.61
Phosphorous (mg/dl)	5.1a	7.1b	7.2b	0.36
Glucose (mg/dl)	66.7	58.3	60.3	6.40
Calcium (mg/dl)	9.4	9.9	10.1	0.28
Total protein (g/dl)	6.5	6.8	7.1	0.21
Albumin (g/dl)	2.35	2.39	2.45	0.092
Globulin (g/dl)	4.1	4.5	4.7	0.024
Albumin:globulin ratio	0.56	0.55	0.54	0.054
Total bilirubin (mg/dl)	0.31	0.36	0.62	0.110
Lactate dehydrogenase (U/l)	895	890	946	57.8
Alkaline phosphatase (U/l)	649	781	786	138.2
Creatine kinase (U/l)	85	105	137	17.5
γ-Glutamyltransferase (U/l)	83.8	85.3	100.3	7.00
Aspartate aminotransferase (U/l)	108.9	92.5	98.1	10.70
Magnesium (mg/dl)	2.25	2.11	2.13	0.079
Osmolality (mosm/kg)	276	268	266	7.6

a and b means in a row without a common letter differ ($P < 0.05$).

[a] Step: dietary cedar foliage level (DM basis) of 0, 1.25, 2.5, 5, 10, 15, 20 and 25% in weeks 1–8, respectively; set: dietary cedar foliage level (DM basis) of 0% in week 1 and 25% in week 2–8; control: 0% dietary cedar foliage level.

was similar among Phase 1 treatments when hay was available. Concentration of carbon dioxide was greatest among Phase I treatments for Control without access to hay and for Step ($P < 0.05$) when hay was available.

Elevated serum AST is indicative of soft tissue damage, increased LDH suggests organ damage, high serum AP, GGT, bilirubin, globulin and urea N and hypoalbuminemia reflect hepatic injury or bile duct obstruction and high creatine kinase and creatinine imply loss of cardiac and muscle mass (Kramer and Hoffman, 1997; Tennant, 1997). Elevated serum AST has been reported with the feeding of redberry juniper (Pritz et al., 1997). The absence of a similar effect in the present experiment may be due to differences in the amount and type of juniper consumed (Riddle et al., 1996; Bisson et al., 2001). That CF consumption did not affect concentrations of blood constituents indicative of negative effects on health status, such as liver or kidney damage, suggests a lack of toxic effects, perhaps since CF was not more than 25% of the diet. Similarly Thompson and Swartz (1990) did not observe negative effects on production (kidding rate and BW gain) of consumption by Angora goats of a level of cedar similar to that in the present study.

Detoxifications usually involve acidification/conjugation pathways for excretion, but no blood parameters in this experiment suggest an overload of acid–base balance. Secondary chemicals often are metabolized to organic acids that are excreted in urine and decrease urinary pH (Dearing et al., 2000). Greatest blood concentration of carbon dioxide among treatments in Phase 1 for Step could reflect greatest toxin clearance, although concentrations in Phase 2 are not in close alignment with differences in CF intake.

Table 10
Effects of method of adaptation to Eastern red cedar foliage on concentrations of blood constituents of Boer crossbred goat wethers fed at a level of intake near maintenance at the end of Phase 3

Item	Hay	Treatment[a]			S.E.
		Step	Set	Control	
Sodium (mmol/l)[b]	Mean	143	145	144	0.8
Potassium (mmol/l)	Hay	5.5 a,b	5.1 a,b	4.9 a	0.21
	No hay	5.2 a,b	4.8 a	5.9 b	
Chloride (mmol/l)[b]	Mean	105	106	105	0.9
Carbon dioxide (mmol/l)	Hay	31.3 c	28.4 a,b	27.6 a	0.71
	No hay	28.4 a,b	26.5 a	30.2 b,c	
Anion gap K+ (mmol/l)l[b,c]	Mean	14.6	15.8	15.1	0.31
Urea N (mg/dl)[b]	Mean	14.2	14.8	14.2	1.17
Creatinine (mg/dl)[b]	Mean	0.79	0.88	0.93	0.044
Urea N:creatinine ratio[b]	Mean	17.9	16.8	15.0	0.83
Phosphorous (mg/dl)[b]	Mean	5.4	6.5	6.8	0.51
Glucose (mg/dl)[b]	Mean	59.1	62.0	61.2	1.66
Calcium (mg/dl)[b]	Mean	9.4	9.5	9.6	0.21
Total protein (g/dl)[b]	Mean	6.6	6.6	6.8	0.13
Albumin (g/dl)[b]	Mean	2.27 a	2.31 a,b	2.42 b	0.034
Globulin (g/dl)[b]	Mean	4.3	4.3	4.4	0.11
Albumin:globulin ratio[b]	Mean	0.53	0.54	0.55	0.015
Total bilirubin (mg/dl)[b]	Mean	0.23 a	0.18 a	0.43 b	0.044
Lactate dehydrogenase (U/l)[b]	Mean	882	987	1052	52.8
Alkaline phosphatase (U/l)[b]	Mean	391	375	337	19.1
Creatine kinase (U/l)[b]	Mean	108	128	136	17.3
γ-Glutamyltransferase (U/l)[b]	Mean	69.7	76.4	84.5	3.84
Aspartate aminotransferase (U/l)[b]	Mean	79.4	81.5	90.1	4.05
Magnesium (mg/dl)[b]	Mean	2.19	2.04	2.14	0.061
Osmolality (mosm/kg)[b]	Mean	274	278	276	1.6

a, b and c means in a row without a common letter differ ($P < 0.05$).

[a] Step: dietary cedar foliage level (DM basis) of 0, 1.25, 2.5, 5, 10, 15, 20 and 25% in weeks 1–8, respectively; set: dietary cedar foliage level (DM basis) of 0% in week 1 and 25% in weeks 2–8; control: 0% dietary cedar foliage level; without or with separate free-choice access to low-quality grass hay.

[b] Nonsignificant cedar foliage × hay treatment interaction ($P > 0.05$).

[c] Significant effect of hay access ($P < 0.05$; 14.6 and 15.7 with and without hay access, respectively, S.E. = 0.25).

4. Summary and conclusions

CF consumed for 7 week at up to 25% of the diet did not adversely affect growth rate or health of yearling goats. Slow, stepwise adaptation to CF resulted in slightly greater CF intake in the last 2 week of adaptation as a proportion of that offered than use of a constant dietary level, although the quantity consumed was similar. Also, without hay access stepwise adaptation yielded greater intake of CF later compared with no earlier exposure or use of the constant dietary CF level when there was no access to a low-quality grass hay. Addition of hay to CF-containing diets did not lessen CF intake, but rather elicited CF intake as great or greater than by goats without access to hay and prevented effects of prior method of adjustment to CF. In conclusion, gradual increases in dietary levels of CF deserve further research as a potential means of elevating present and future CF consumption, but with attention directed to type and level of other feedstuff offered.

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